OBSERVATIONS IN FIVE HUNDRED CASES OF INJURIES OF THE PERIPHERAL NERVES AT U. S. A. GENERAL HOSPITAL NO. 11

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and
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OF the 208,000 casualties in the American Expeditionary Force, there were in the general and base hospitals in this country in April, 1919, 3,000 patients with peripheral nerve injuries. Assuming that 15 per cent of the total admissions had been discharged by this time—a conservative estimate—there were altogether approximately 4,500 peripheral nerve injuries or 1.6 per cent of the total casualties.

With but few exceptions, the treatment of peripheral nerve injuries did not begin until the soldiers from overseas became patients on this side of the Atlantic. Obviously this was a problem which belonged to the reconstruction hospitals and not to the hospitals of the war zones. In more than 500 cases admitted to General Hospital No. 11, there were not more than 5 cases in which the nerve had been sutured overseas.

The Surgeon General recognized in the management of peripheral nerve injuries a problem quite distinct from that either of general or orthopedic hospital and authorized the organization of ten peripheral nerve centers, in as many general hospitals, to which all patients were to be transferred from the ports of debarkation or later from base hospitals, to which a number found their way with lesions of the nerves unrecognized at the time of their admission. In each of these peripheral nerve centers an officer, experienced in neurological surgery, was assigned and a consulting neurologist and equipment essential for examination and treatment were provided. As an additional recognition of the importance of the peripheral nerve problem, the Surgeon General approved the organization of a Peripheral Nerve Commission, selected the personnel, and issued instructions as to the scope of its work. Among other things this commission will prepare for the Surgeon General a comprehensive report dealing with the various aspects of peripheral nerve injuries and the results obtained by treatment.

It has been my privilege as consultant in neuro-surgery to the Surgeon General's office, to visit the clinics in many of the peripheral nerve centers, but the views herein expressed will be based more particularly upon the observations of between five and six hundred cases under my direct supervision at General Hospital No. 11 (Table I).

To systematize the preparation of the clinical records, printed forms were prepared, afterward adopted by the commission as the authorized form for all the peripheral nerve centers. A technique of examination was elaborated, special instruments were designed, and instructions were issued as to how the phenomena were to be elicited and recorded. Orders were issued that duplicate copies of all clinical records be furnished to the Surgeon General's office so that the Commission might have, as the basis for its final report to the Surgeon General, complete and uniform records of all peripheral nerve lesions standardized as to methods of examination and record.

SENSORY PHENOMENA

With regard to observations upon disturbances, we disregarded the theory of Head and his well known classification of "epicritic" and "protopathic" sensory loss. The subsequent experiments of Trotter and Davis[1] and later of Boring[2] proved the fallacy of Head's theory and disproved the idea that there are separate fiber systems for moderate (epicritic) and for extreme (protopathic) temperature, tactile, and pain sensibility. Furthermore, the clinical observations from the wealth of material, provided by the four years of war, may be cited in refutation of Head's classification. Lieutenant Cobb, from his review of the literature and from his study of the problems in our clinic, concluded that dissociations of sensation due to peripheral

[1] J. Physiol., 1909, xxxviii, 134.
[2] Quart. J. Exp. Physiol., 1916, x. 1.

* The views expressed in the observations recorded in this article represent those of my associates on the staff as well as my own. I am indebted to the cordial co-operation of Majors Coleman and Selling, Captains Ingham, Kraus, and King, First Lieutenants Arnett, Anderson, Baird, Behnev, Buerki, Cobb, Hobson, Kennedy, McCutcheon and Silbert.

TABLE I.—TABLE SHOWING NERVES INVOLVED IN A SERIES OF 400 CASES

Upper extremity		Percentage
Ulnar	112	22
Musculospiral	96	18.9
Median	88	17.3
Brachial plexus	37	7.2
Musculocutaneous	13	....
Facial	13	....
Internal cutaneous	9	....
Circumflex	5	....
Radial	2	....
Lingual	1	....
Hypoglossal	1	....
Supraspinatus	1	....
Total	378	74.5

Lower Extremity		Percentage
Sciatic	53	10.4
External popliteal	53	10.4
Internal popliteal	11	2.1
Anterior tibial	4	....
Posterior tibial	2	....
Lumbar plexus	3	....
Small sciatic	1	....
Anterior crural	1	....
Musculocutaneous	1	....
Total	129	25.5

nerve lesions arose from comparing stimuli, not only quantitatively different but qualitatively unequivalent. By varying the quantitative values of the stimuli, dissociations of sensations could be produced almost at will. In short they are artefacts due to lack of proper standardization of the examination. Hence, it became apparent that in the examination of disturbed sensation, standardized instruments had to be employed and the examinations conducted under uniform conditions. If the limb was cold at one examination and warm at another, there would be a difference of 0.5 centimeters to 2.0 centimeters in the ulnar and even 5 centimeters in the sciatic distribution.

Upon the adoption of standardized algesimeters and a uniform technique, it was found that in the examination of an individual case by different members of the staff the sensory charts were precisely similar (Fig. 1). The technique included:

a. An examination for tactile sensibility with a camel's hair brush, so pliable that the skin could not be depressed. Loss to tactile sensibility was indicated on the chart by lines representing the stroke of the brush.

b. Test for pain sense with an algesimeter with 15 grams' pressure, indicated when lost by large dots on the sensory chart (see Fig. 2).

c. Test for deep sensibility by an algesimeter with 1000 grams' pressure indicated when lost by small dots or solid black (see Fig. 2).

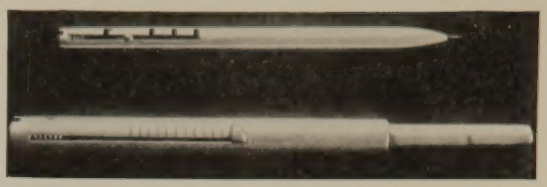


Fig. 1. Æsthesimeters devised at U. S. A. General Hospital No. 11 by Captain Ingham.

ELECTRICAL EXAMINATIONS

Electrical stimulation of muscles or nerves at the evacuation or base hospital is an invaluable aid in distinguishing the organic from the functional paralysis. In the reconstruction hospital where the patients are received 3 to 6 months after the injury, the value of the electrical examination is twofold: (1) to observe evidences of recovery, (2) to determine whether the condition is stationary or retrogressive. In recording the electrical findings, a special chart is used and instructions issued to all peripheral nerve centers as to how the findings are to be recorded (Fig. 3). We eliminated the terms "Reaction of Degeneration" as indicating conclusions rather than observations and instructed the examiner to record precisely what he elicited: (1) whether "faradic" contractions were "normal," "weak" or "absent," and (2) in the galvanic stimulation the rapidity of the contractions and relaxations and the presence or absence of reversals. By this system of record, comparisons could be made between examinations of different dates. The instrument supplied to all peripheral nerve centers was the Wappler galvanic and faradic plate. The investigation and interpretation of the electrical findings at General Hospital No. 11 is under the direction of Lieutenant Silbert, and the following are some of his deductions:

1. The loss of skin sensibility to faradic current is fairly good evidence of complete interruption. Tinel's observation that the return of skin sensibility is the earliest sign of nerve regeneration has been confirmed by the examinations in this clinic.

2. Occasionally the loss of skin sensibility is incomplete in cases proved at operation

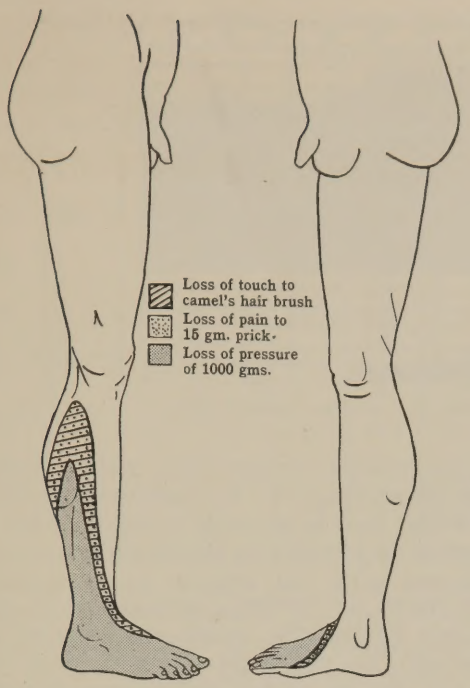
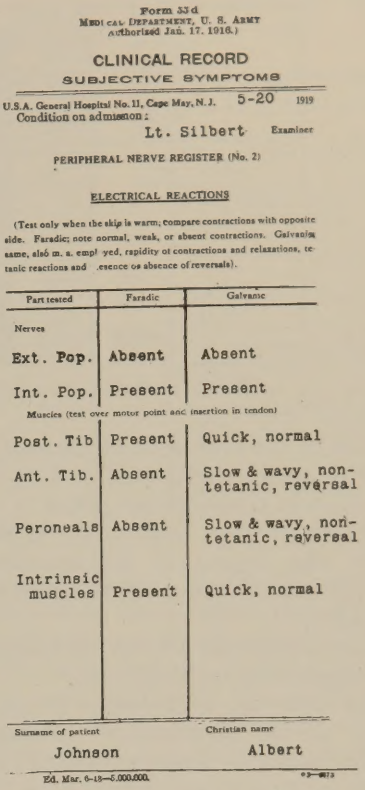


Fig. 2. Chart showing method of recording sensory examination.



Form 53 d
MEDICAL DEPARTMENT, U. S. ARMY
(Authorized Jan. 17, 1916.)

CLINICAL RECORD
SUBJECTIVE SYMPTOMS

U.S.A. General Hospital No. 11, Cape May, N. J. 5-20 1919
Condition on admission:
Lt. Silbert Examiner

PERIPHERAL NERVE REGISTER (No. 2)

ELECTRICAL REACTIONS

(Test only when the skin is warm; compare contractions with opposite side. Faradic; note normal, weak, or absent contractions. Galvanism same, also m. a. empl yed, rapidity of contractions and relaxations, tetanic reactions and .esence or absence of reversals).

Part tested	Faradic	Galvanic
Nerves		
Ext. Pop.	Absent	Absent
Int. Pop.	Present	Present
Muscles (test over motor point and insertion in tendon)		
Post. Tib	Present	Quick, normal
Ant. Tib.	Absent	Slow & wavy, non-tetanic, reversal
Peroneals	Absent	Slow & wavy, non-tetanic, reversal
Intrinsic muscles	Present	Quick, normal

Surname of patient: Johnson
Christian name: Albert

Ed. Mar. 6-18—5,000,000.

Fig. 3. Chart showing method of recording electrical examination.

to be complete interruption. This phenomenon has been attributed to the presence of anastomotic communications between the nerves below the level of the lesion.

3. Faradic response may be lost even in incomplete and mild lesions, and such as those of moderate contusion, and is, therefore, of little value in a decision for or against operation. With but one exception in the operative series and in but three of all other cases did voluntary motion not return before that of response to the faradic current.

4. Stimulation by galvanism applied over the course of the damaged nerve uniformly fails to give a response in the muscles below the level of the injury.

5. The following deductions are drawn from the application of galvanism to the muscles supplied by the damaged nerve:

a. The maximum response is usually over

TABLE II. — SUMMARY OF ELECTRICAL EXAMINATIONS IN 100 CASES OPERATED UPON

	Faradic						Galvanic											
	Area of loss of skin sensibility			Muscle response			Nerve response			Muscle response								
										Slow			Tetanic			Reversal		
	Present	Absent	Not recorded	Present	Absent	Not recorded	Present	Absent	Not recorded	Present	Absent	Not recorded	Present	Absent	Not recorded	Present	Absent	Not recorded
Compression	1	3	6	0	10	0	0	10	0	9	0	1	1	5	4	1	4	5
Neuroma	20	17	15	0	52	0	0	50	0	50	0	2	6	30	16	11	38	3
Interruption	13	8	17	0	36	2	0	36	1	36	0	2	1	27	10	20	15	3

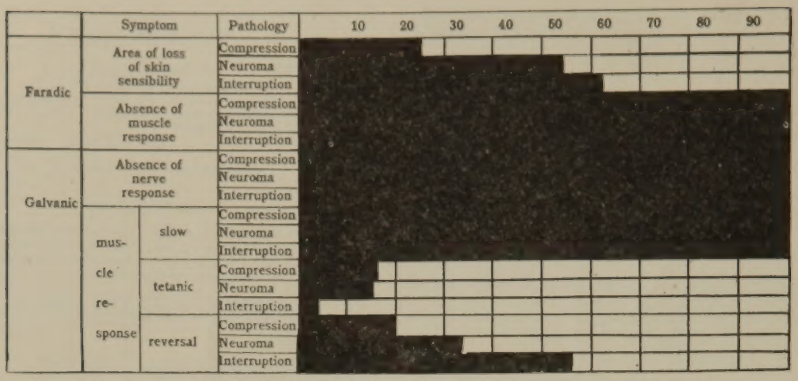


Table III. Summary of electrical examinations in 100 cases operated upon.

the tendon of the muscle or at the junction of tendon to muscle belly and not as in the normal muscle at the motor point.

b. The rapidity of contraction is the best guide to the degree of degeneration; the slower the reaction the more complete the degeneration.

c. Tetanic response is observed occasionally but its significance is not clear.

d. The reversal of polarity is the most valuable of all phenomena. Though not invariably yet in the majority of cases reversal signifies anatomical interruption.

e. Reversal of polarity is occasionally seen in normal muscles (see Tables II and III).

TROPHIC AND VASOMOTOR DISTURBANCES

Trophic and vasomotor disturbances of peripheral nerve lesions, are frequently observed but are of comparatively little practical importance, as affecting diagnosis, prognosis, or treatment. Capsular and muscle fibrosis are the most serious complications of peripheral nerve lesions and they are introduced in this connection because so often vaguely attributed to trophic influences. This disability arising from these two factors is extreme and unless relieved the regeneration of the injured nerve will avail but little. For reasons not clear the metacarpophalangeal joints are the most seriously involved. The cause of these crippling lesions in muscle and joint has been the object of an investigation in our clinic by Major Selling, and he has come to these conclusions: (1) In uncomplicated lesions there is no limitation of passive motion, except that which results from shortening of the paralyzed muscle, when the limb is properly splinted. This is of minor importance as the disability is soon overcome after the muscles have regained their function. (2) When nerve injury is complicated by fracture, prolonged immobilization and particularly by suppuration in the healing process, the result is often capsular fibrosis no matter what the nerve involved, whether musculospiral, ulnar or median. (3) If, however, there is a serious vascular lesion of the main arterial trunks, added to the capsular fibrosis, there is extensive muscle fibrosis and the combination of these is responsible for the extreme limitation of motion. The fact that in median and ulnar lesions of the arm, there is greater likelihood of involvement of the main arterial trunks accounts for the fact that these crippling deformities are seen more often in median and ulnar than in musculospiral lesions; and the same line of reasoning may be applied to

TABLE IV.—FACTORS INVOLVED IN LIMITATION OF MOVEMENT

1. Direct damage—joint and muscle.
2. Fibrosis and shortening paralyzed muscle.
3. Adaptive shortening normal muscle.
4. Capsular fibrosis.
5. General muscle fibrosis.

Nerve lesion.	*Limitation Joint Movement.*
1. Uncomplicated	
	a. absent
	b. due to shortening of paralyzed muscles
2. Complicated by	
a. fracture	
b. immobilization	Capsular fibrosis
c. suppuration	Other factors secondary
3. Complicated by vascular lesion	Capsular fibrosis Extensive muscle fibrosis and shortening.

TABLE V.—FACTORS IN JOINT LIMITATIONS IN A SERIES REPRESENTING THE MUSCULOSPIRAL, MEDIAN, AND ULNAR

Name	Lesion	Location	Fracture	Suppuration	Immobilization	Vascular	Elbow	Wrist		Fingers Limited Movt. Due to	
								Flex.	Ext.		
W. C.	M. S.	Arm	O	O	O+	O	O	+++	O	O	Wrist flexion; shortening of extensors.
W. C.	Med.	Axilla	O	O	O	O	++	O	++	O	Elbow direct injury. Wrist ext.; shortening of flexors.
P. H.	U.	Arm	O	O	O	O	O	O	+	O	Wrist ext.; shortening of flexors.
H. D.	M. S.	Arm	Humerus	+++	+++	O	+++	+++	++	++	Joint involvement (capsular fibrosis) all joints.
E. E.	Med.	Arm	Elbow	+++	+++	O	++++	+++	+++	+++	Joint involvement all joints. Elbow direct injury; others capsular fibrosis.
B. H.	Ulnar	Arm	Elbow	+++	+++	O	++++	+++	+++	++	Joint involvement all joints. Elbow direct injury; others capsular fibrosis.
H. H.	Med. Ulnar	Arm	O	+	++	Oblit. Brachial Artery	+++	+++	+++	+++	Joint involvement all joints. Capsular fibrosis and extensive muscle fibrosis.

the lower extremity, where the most commonly affected nerve, the sciatic, is not accompanied with an injury of the large vascular trunks (see Tables IV and V).

PATHOLOGICAL CONSIDERATIONS

The pathology of peripheral nerve lesions was not overlooked in the turmoil of war, and of the noteworthy investigations mention should be made particularly of those of Cone and those of Huber, to whose direction the Surgeon General assigned the experimental study of nerve regeneration, as applied to nerve suture, and the minute examination of the pathological material removed at operation in the several peripheral nerve centers. The various types of lesions have been classified under five headings.

1. Complete anatomical interruption
   a. with central bulb,
   b. with central and peripheral bulb;
2. Neuroma in continuity
   a. central bulb;
   b. lateral bulb;
3. Partial anatomical interruption (lateral notch);
4. Sclerosis;
5. Compression
   a. by callus, bone spiculi,
   b. by aneurism,
   c. by scar tissue.

The pathological investigations in our clinic have been made, apart from the routine examination of specimens, chiefly along two lines; the topographical study of specimens removed with relation to the results of electrical stimulation on the operating table, and the distribution of motor and sensory disturbances and the correlation of pathological and electrical findings.

With regard to the latter, the complete and incomplete sensory, motor, and electrical findings have been tabulated in Table VI with relation to the three essential lesions: compression, neuroma in continuity and complete anatomical interruption. It is of interest to note that in the majority of instances a careful examination of motor, sensory, and electrical disturbances foretold the character of the lesion found on the operating table. Thus (1) in compression there was complete motor paralysis in 45 per cent, complete sensory loss in 15 per cent, and no case with complete reactions of degeneration. (2) In complete anatomical interruption there was complete motor loss in 100 per cent, complete sensory loss in 86 per cent and complete reactions of degeneration in 85 per cent. (The absence of complete sensory loss or reaction of degeneration in the minority may be attributable to the fact that in the scar tissue intervening between the divided seg-

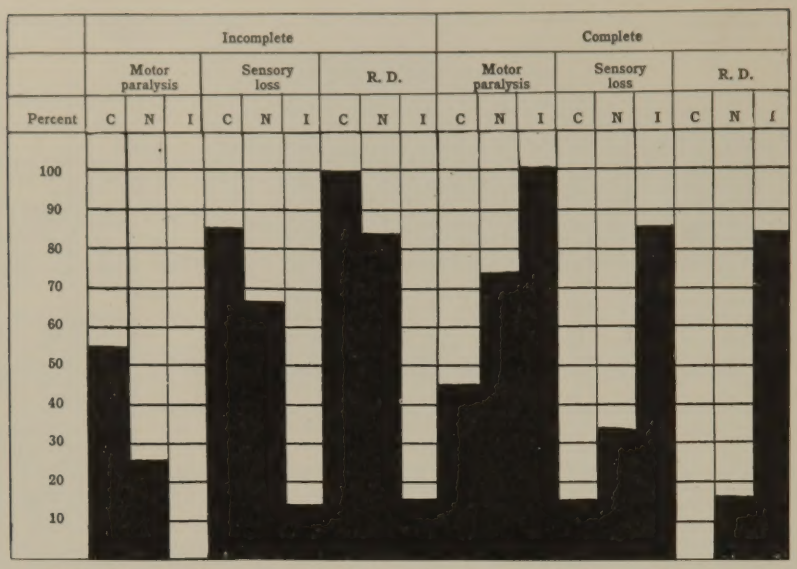


Table VI. Showing percentage of incomplete and complete motor, sensory, and electrical syndromes in compression, *C*, neuroma in continuity, *N*, and anatomical interruption, *I*.

ments a few indistinguishable fibers may have been present.) (3) The neuroma in continuity presented a picture, as one might expect, intermediate between compression and complete interruption. Thus there was complete motor loss in only 74 per cent, incomplete in 26 per cent; complete sensory loss in only 33 per cent, incomplete in 67 per cent; complete reaction of degeneration in 16.5 per cent, incomplete in 83.5 per cent.

TIME OF OPERATION

The determination when to operate is a matter of vital importance. Without fear of contradiction it can be assumed that the sooner the operation the better, but from indiscriminate, hasty resort to operation one must refrain for two reasons: (1) because many cases will recover spontaneously; (2) because the presence of an infected wound necessitates postponement. Looking at the statistics in our own clinic, we find that the first signs of recovery were not observed in a number of cases until 8 months after the injury (see Table VII). Of the recovering cases, 36 showed the first signs of recovery in the fifth and sixth month, and 26 in the seventh and eighth month. From these figures and those in the table it would be evidently unjustifiable to resort to operation, at least until six months had elapsed, and there might in view of these figures be some justification for waiting a month or two longer. The percentage of spontaneous recoveries may vary in different clinics. At General Hospital No. 11, taking the last 400 cases, 254 or 63 per cent had recovered sufficiently to be discharged or were in the recovery stage, 112 or 28 per cent had been operated upon and 9 per cent were stationary and unimproved (Table VIII).

TABLE VII.—SHOWING THE FIRST RECORDED SIGNS OF RECOVERY IN A SERIES OF 400 CASES

	Cases	Percentage
2 months	13	3
3 months	34	8.5
4 months	71	17.7
5 months	77	19.4
6 months	67	16.8
7 months	61	15.3
8 months	45	11.3
Over 8 months	32	8
	400	

Viewed from the standpoint of the condition of the wound, the advisability of waiting until the wound has been healed 3 months has been recognized as a wise precautionary

TABLE VIII.—SHOWING THE DISPOSITION OF A SERIES OF 400 CASES

Cases discharged—		
Operated upon	3	
Not operated upon	125	128
Cases remaining—		
Operated upon	109	...
Not operated upon	...	...
Improving	129	...
Stationary	34	272
Total		400

TABLE IX

Time it took wound to heal in a series of 400 cases	Cases	Time of operation if performed 3 months after wound healed	Percentage
1 month or less	126	4 months	31.5
2 months	90	5 months	22.5
3 months	74	6 months	18.5
4 months	36	7 months	9
5 months	26	8 months	6.5
6 months	17	9 months	4.3
7 months	6	10 months	1.5
8 months	6	11 months	1.5
9 months or over	19	12 months	4.7
Total	400		100.00

measure. This has been our practice, and the fact that there have been but three infections in over 100 elaborate, extensive and prolonged dissections, often through poorly nourished tissue and extensive cicatrization, would appear to justify the adoption of the three month rule. Two of these wound infections were superficial and could not have affected the process of regeneration at the line of suture; in one instance recovery has been complete. Applying the three month rule to our own cases (see Table IX) the time of operation would have been deferred to the end of the fourth month in 33 per cent of cases, to the end of the fifth and sixth month in 44 per cent, and to the end of the seventh and eighth month in 15 per cent. Apart from the interpretation of clinical phenomena as indicative of a complete physiological block, these two factors, the chance of spontaneous recovery and the three month rule, are often the decisive factor in determining how soon the patient should be operated upon.

METHODS OF PROCEDURE

Splinting. In the organization of a peripheral nerve clinic, provision must be made for the care of those cases in which spontaneous recovery has already begun as well as for those in which the necessity for operation is still under consideration. The importance of keeping the muscle in a state of rest was recognized long before the war and in lesions other than peripheral nerve palsies. It had been observed in the paralysis of anterior poliomyelitis that when muscles were kept at rest by proper apparatus, recovery of function was more prompt in the first place and in the end more complete. This general principle was recognized in the case of the peripheral nerve palsies, but there is a threefold purpose in the employment of splints. Not only is the muscle maintained in a state of rest, but overstretching of muscle and tendon is prevented and what is of equal importance, contraction and shortening of the antagonistic muscle is impossible.

In our clinic many of the splints employed were designed by Lieutenant Buerki, others were adopted from those in use in other clinics. The splints for musculospiral and external popliteal paralysis and for cases recovering from operation upon the sciatic or popliteal nerves were made after Lieutenant Buerki's designs (see Figs. 4 to 9). The splint for the median and ulnar paralysis was fashioned after the pattern of that used at the Walter Reed General Hospital and that for the brachial plexus palsies after the splint used at General Hospital No. 9. The essential features of a serviceable splint are these: it should be comfortable, light in weight, not cumbersome, of simple construction, easily removed and retained in position without bandages. All the splints in our clinic met these qualifications and were made in the splint room, by unskilled hands, out of heavy steel or copper wire. Especial emphasis is laid upon the avoidance of the bandage in the application of the splint because splints must be removed daily when the patient receives massage or while he is employed in the curative workshop.

Physiotherapy. In all peripheral nerve clinics the physiotherapy department is regarded as an essential feature of the organization and serves a useful purpose. While neither massage nor electricity can in the smallest degree prevent the atrophy of a muscle once its nerve supply has been interrupted, manipulation by massage and passive motion will aid in mobilizing joints that are restricted in movement for one cause or

Fig. 4.

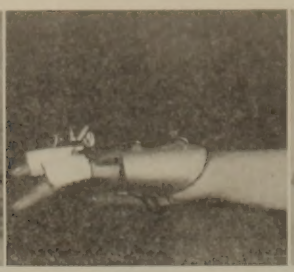


Fig. 5.

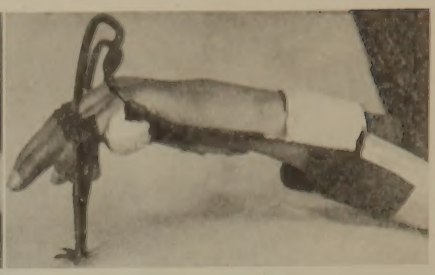


Fig. 6.

Fig. 4. Splint for musculospiral paralysis.
Fig. 5. Splint for ulnar paralysis.
Fig. 6. Splint for median paralysis.

another. Contraction of the paralyzed muscles by electrical stimulation is a valuable substitute for massage, and especially in the operative cases, it is of untold value from a psychological point of view, in that during the long and trying period, both before and after operation, the patient is content in the belief that by some magic influences electricity will restore power to the palsied limb.

For the recovering cases the curative workshop plays an important rôle. There is no doubt that purposeful movements are more effective in the restoration of function than calisthenics, passive movements, or massage. Furthermore the patient himself is much more content, his morale better, when his time is occupied in some form of occupation which maintains his interest.

Secondary débridement. In many instances it was necessary to postpone operation because of unhealed wounds. In many of these there was a chronic osteomyelitis. The postponement of nerve suture for weeks or months was, together with prolonged suppuration, prejudicial to the ultimate recovery of function. To hasten the healing of the wound, Captain King proposed a preliminary débridement with disinfection of the wound by the Carrel-Dakin technique, and when the wound was sterile, secondary closure, filling the defect if any, with a fat transplant. This plan of procedure was put in effect with the happiest result and final healing was secured in three or four weeks in wounds which, if left to the natural processes of repair, would have continued unhealed for as many months (Figs. 10 and 11).

In a paper which touches upon the problems of peripheral nerve lesions from so many angles, it will be impossible to include in the discussion of the technique the many details as they affect the individual nerves. The various steps of the operation will be reviewed as in its wider application and as practiced at General Hospital No. 11. To begin with the incision must extend well above and below the lesion. In the arm it is frequently necessary to make an incision from the axillary fold to the elbow or below, if the ulnar is to be transposed. The nerves must first be exposed and identified well above and below the lesion and then traced as far as possible through the entangling scar tissue. Frequently it is necessary to mobilize the nerve for a considerable distance above and below the lesion to secure approximation after resection.

Instead of towels as wound protectors, we have used a sterile sleeve slit the length of the wound and secured over the edges of the wound with Backus forceps. This enables the position of the arm to be changed, as is so often necessary, with greater facility than if draped with towels.

The dissection itself is one of the most tedious of surgical procedures. An abundance of scalpels is necessary since the edge is soon blunted by the dense connective tissue. While sharp dissection with the scalpel is to be preferred in general, we have found a small pair of eye tenotomy scissors convenient in freeing the nerve at the point it enters the dense scar tissue where it is difficult to distinguish between the two (Fig. 12). There are many objections to the use of the tourniquet and to avoid the necessity of constant sponging in order to keep the field clear, since oozing is

Fig. 7. Splint for deltoid paralysis.

Fig. 8 (at left). Splint for external popliteal paralysis.
Fig. 9. Splint for sciatic paralysis.

continuous, we have found a continuous stream of normal saline solution, directed precisely at the point of dissection to possess many advantages. The constant oozing is an annoying feature, constant sponging traumatizes the tissues and the continuous play of solution upon it keeps the field clear. When sponging is necessary, small pledgets of cotton should be used.

Electrical stimulation. Electrical stimulation of nerves on the operating table may serve a twofold purpose. Occasionally the identification of individual nerves in the upper arm or of roots or cords of the brachial plexus is facilitated by the use of the battery. But more frequently we have found it of service in deciding whether resection is or is not appropriate and how much if any of a given nerve may be conserved. Occasionally the external appearance of the nerve might not justify resection; if faradization of the nerve is followed by a response, resection would be clearly contra-indicated. If doubt still exists as to the propriety of resection we have in some instances split the sheath of the nerve and applied the electrode directly to the fasciculi. By this procedure we have been able to conserve some fibers which otherwise would have been sacrificed. Apart from the practical value of faradization we have been able to make, under the direction of Captain Kraus, interesting observations as to nerve topography. For example, we have found which portions of the circumference of the median nerve are purely sensory and might be sacrificed where it is desirable to use the median as a receptor for lateral implantation suture, as of the ulnar or musculospiral nerves.

Further interesting observations have been made as to the results of nerve stimulation of the peripheral segment after the nerve has been divided preliminary to suture. In one instance the musculospiral, clinically quite unreactive to the faradic and showing a partial reaction of degeneration (no reaction of the nerve to galvanism and slow contraction of the muscles without any polar reversal) gave, on stimulation of the distal end at operation, a definite response in the extensor indicis. In another instance the median nerve was found divided, but stimulation of the peripheral stump gave reactions in the flexors of the fingers and in the pronator radii teres. We shall need pathological confirmation of the absence of connecting fibers in the surrounding tissues. Another type of electrical response has been the presence of faradic reaction at operation but not clinically, with no visible discontinuity of the nerve present. A much stronger current is needed to bring about these reactions in diseased nerves than is needed to stimulate a normal nerve.

Resection. In the final analysis the success or failure of nerve suture depends upon

whether or not both central and peripheral segments contain healthy fasciculi free from the entanglements of adventitious connective tissue. The regeneration processes of nature are so well performed that given healthy fasciculi, regeneration will occur in spite of a clumsy suture. Hence all depends upon the judgment of the operator as to how much tissue is resected from either segment. The inclination is to resect as little as possible in contemplation of the difficulties in bridging the defect. But this must be disregarded and the criterion always must be the appearance of the nerve on cross section. With a safety razor, section is made at intervals of 2 to 3 millimeters until the appearance of the cross section is that of normal fasciculi. It is surprising how completely the picture will change, when the sections are made but 2 millimeters apart, from one in which the fasciculi are embedded in scar tissue to one in which there appears to be no scar tissue at all (see Fig. 17). The variation in the number of fasciculi in the central and peripheral segments is usually very great; there may be 8 or 10 in the central segment of a musculospiral nerve and only 3 in the peripheral segment. The actual resection should not be begun until all is in readiness for suture. All bleeding should be controlled, the bed of the nerve prepared and if stretching is necessary to aid in bridging the defect, this may be applied by traction on the bulbous ends.

Suture. The final approximation of the divided segments may be accomplished alone by through-and-through tension suture or together with interrupted sutures in the perineurium. We have employed the latter technique striving to secure accurate opposition of the sheath in the belief that by so doing, the neuraxes will be directed with greater certainty from the central to the peripheral segment. One through-and-through chromic catgut suture is used as a stay suture to prevent tension upon the fine silk perineural sutures and at the same time

Fig. 10 (at left). Wound after débridement and Dakinizing before suture.
Fig. 11. Wound after secondary suture.

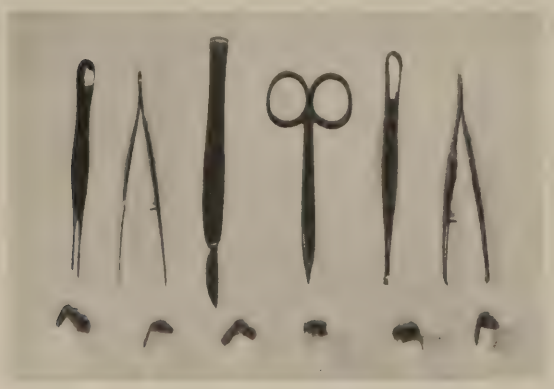


Fig. 12. Instruments used in nerve suture.

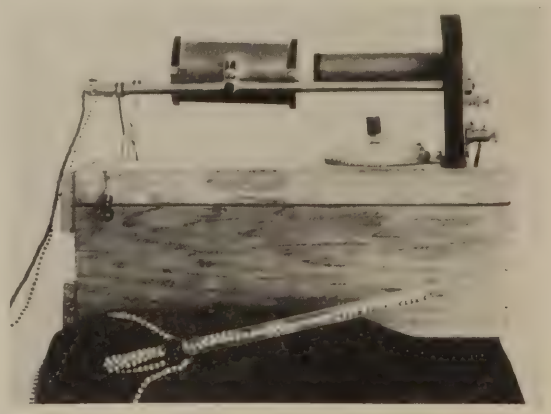


Fig. 13. Battery and electrode used in stimulation of exposed nerves at operation.

Fig. 14. Method of stimulating nerve exposed at time of operation.

to obliterate the space between the segments. If perineural sutures alone were used this space would fill with blood clot which when organized would offer a barrier to the passage of the new axis cylinders. Four to six silk sutures suffice to secure accurate apposition of the perineurium. There are two points in the technique of suture worthy of attention. In the first place the stay suture should not be tied, when there is any tension, until the perineural sutures are introduced and tied. To tie the tension suture first will cause the fasciculi to protrude on either side and make it difficult to keep them within the sheath as the perineural sutures are tied. This may seem to be a minor matter, but by observing this precaution a real difficulty in nerve suture will be avoided. The second point has to do with the prevention of rotation in suture and the preservation of nerve pattern. Before the nerve is dissected from its bed guide sutures of silk are introduced at corresponding points on the circumference of central and peripheral segments (see Fig. 18). If this precautionary measure is not adopted the operator can never be sure that, after the two segments have been freed a considerable distance above and below the lesion, there will not be some rotation. Whether the avoidance of rotation is of real or only of theoretical importance might be open to discussion. Langley[1] is of the belief that accuracy in apposition is one factor determining the degree of recovery. By distortion of the nerve pattern the central nerve cells, which

Case No. Date of Admission

Name Rank Co. Organ.

General Hosp. 11 Reg. No. Date of Exam.

Home Address Age

DIAGNOSIS

Electrode Uni — Bi.

Level of Lesion Nature of Lesion

Level of Stimulation Operation

Level of Bifurcation Operator

Muscles Key X O	Result R	Result L	Black — Cephalad, Caudad, Post., Ant. White — Cephalad, Caudad, Post., Ant.

Pathological Findings

Fig. 15. Chart used in recording findings from electrical stimulation at operation.

[1] Brit. M. J., 1918, 1, 45.

Fig. 16. Shows method of sectioning nerve with safety razor.

formerly controlled only a flexor muscle, may, after suture and regeneration, control flexor, extensor, adductor, abductor or rotator muscles in various proportions. If a sensory filament unites with a motor there may be a functionless union. Hence it is concluded that any procedure which reduces disturbance of nerve pattern will make recovery more complete and will shorten the time taken to procure that degree of recovery.

With careful suture of the nerve sheath all forms of so-called protection to the line of suture are not only unnecessary but we believe undesirable. Fascia, fat, the use of Cargile membrane, increase rather than diminish the tendency to connective-tissue formation. A suitable nerve bed is desirable and the best is an intermuscular plane. The old bed of scar tissue or flaps of muscle tissue are both objectionable. When a bed in the normal strata is not available there is no objection to transposing the nerve to a plane between the superficial and deep fascia.

The wound should be closed with interrupted sutures, tier by tier, in muscle, fascia and skin, as far apart as possible, so as to permit of the escape of lymph and serum that would inevitably accumulate were the sutures too close together. With this precaution drainage will be unnecessary.

In most instances the limb, forearm, or leg must be retained in a position of flexion to relieve tension. This position is secured by a lateral plaster-of-Paris splint. It has been our practice to maintain the limb in the position in which it was placed at the time of suture for from four to six weeks, four in the upper and six in the lower extremity. The limb is gradually brought into extension during the succeeding four weeks. Daily massage is given from the day the sutures are removed and galvanism is applied at the same time.

After suture of the sciatic and popliteal nerves the plaster-of-Paris splint is removed at the end of the second week and a light wire splint substituted (see Fig. 9). This splint permits of flexion of the knee but not of extension beyond the desired point. When the time comes to begin extension, this is regulated by daily straightening the splint a little.

SUMMARY

While in this discussion it has not been possible to take up the technical details as

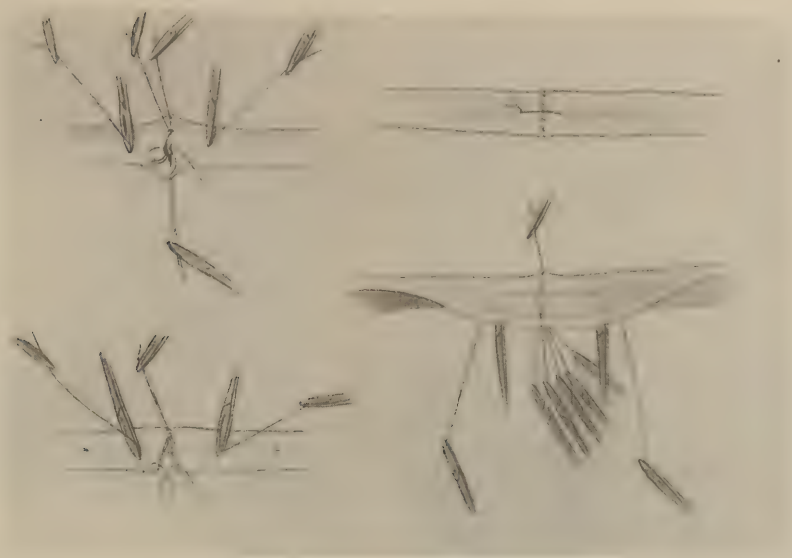


Fig. 18. Steps in technique of nerve suture.

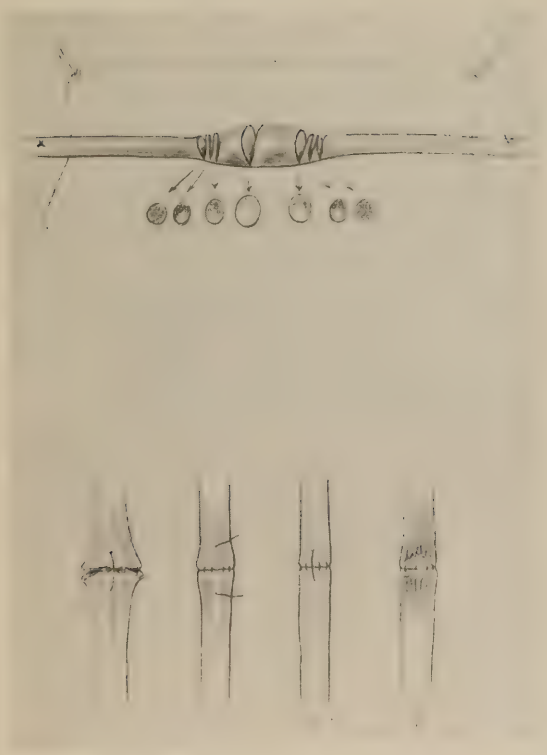


Fig. 17. Steps in technique of nerve suture.

applied to individual nerves, a summary is given in conclusion of the principles which have governed us in dealing with the problems applicable to all.

1. Liberation or neurolysis has been given preference in the absence of a complete anatomical division or a neuroma in continuity when after excising all scar tissue and laying bare the nerve sheath there is a quick response to faradism.

2. Resection and suture are essential whenever neurolysis is contra-indicated. Resection must be carried central and distalward until healthy scar-free fasciculi are exposed.

3. In bridging defects the nerve transplant must not be employed until advantage has been taken of every other reasonable measure: to wit, nerve stretching, immediate or continued (as with sutures through bulbs), mobilization, transposition as of ulnar and musculospiral, and in exceptional instances lateral implantation suture as ulnar or musculospiral into median.

4. When these fail a nerve transplant is justifiable, the autotransplant being the first choice, and homotransplant (preserved in vaseline, liquid petrolatum, or 50 per cent alcohol), the second choice. For autotransplant the musculocutaneous or sural nerves

Fig. 19. Patient with recovering paralysis of external popliteal nerve using jig saw for curative purposes.

of the leg, the radial or internal cutaneous of the arm, may be selected on the basis of convenience.

5. In nerve suture it is equally important to know what one ought not to do. In this category we include suture á distance, the flap operation, bilateral anastomosis (as recommended by Hofmeister) and tubulization.

6. Sharp clean dissection, careful hæmostasis, the approximation of healthy fasciculi, without undue tension, represent the tripod upon which the success of nerve suture rests.

Fig. 20. Handle of saw made to fit paralyzed hand by means of modeling compound.

7. Tendon transplantation should be employed when suture fails and is particularly appropriate in residual palsies of the posterior interosseous, with inability to extend wrist or fingers, and anterior tibial palsies with resulting foot drop.

8. The after-treatment should include (a) enforced fixation for a period of 4 to 6 weeks with gradual straightening of the limb, (b) massage and galvanism until voluntary movement returns, (c) exercises varied according to the muscles involved and with a view of sustaining the interest of the patient.